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DEVELOPMENT OF THE SRE MARK II SAFETY ROD

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ATOMICS INTERNATIONAL

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DEVELOPMENT OF THE SRE MARK II SAFETY ROD

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ABSTRACT

The SRE Mark II safety rod consists of a neutron absorbing column suspended from an electromagnet, which, when de-energized, allows the column to fall into the reactor core. The kinetic energy of the falling column is expended in a gas-compression shock absorber. The poison column is returned to the storage position by an electromagnet attached to a chain drive which is coupled to a position-indication system. The electromagnet has been tested for electrical characteristics, holding force, and release time. An effective insertion time of 0.7 second was measured for the entire rod.

I. INTRODUCTION

The Sodium Reactor Experiment, which was constructed as part of the jointly-sponsored program of the AEC and private industry for the development of nuclear power, is an experimental facility for the exploration and improvement of the technology of sodium-cooled, graphite-moderated reactors. Among the components of the reactor system which required development to ensure satisfactory operation were the safety rods. The first design of SRE safety rod that was chosen for development, designated Mark I, was found to require more extensive proof-testing of high-temperature materials than could be encompassed within the SRE construction schedule. Although Mark I was brought to an advanced state of development and was used for a short time in the SRE,[1] it was decided to proceed with the development of an alternate design. The Mark II design reflects the development experience gained from Mark I, which showed that it was necessary to relocate the moving mechanism portions of the assembly to low-temperature regions in order to reduce difficulties with materials. Consequently, the poison release mechanism, the snubber, the drive mechanism, the position-indication system, and the limit switch system were all located above the reactor loading face in Mark II, where operation is at the ambient temperature of the SRE building. All of the equipment so located is housed in a single demountable unit. This unit is removed prior to fuel charging or discharging operations. Figure 1 is a photograph of the top of SRE, showing the above-shield portions of the Mark II safety rods in place.

The SRE Mark II safety rod was designed to satisfy the following criteria:[2]

a) When signaled by an interrupted electrical circuit, the neutron absorbing material must fall into the reactor under the acceleration of gravity.

b) An electrical indication (which can be used as an interlock) must be provided when the poison column is fully inserted in the reactor core.

c) A device must be provided to retrieve the poison column from the reactor core to the cocked position.

d) A device must be provided to release the poison column at any time during retrieval from the reactor core.

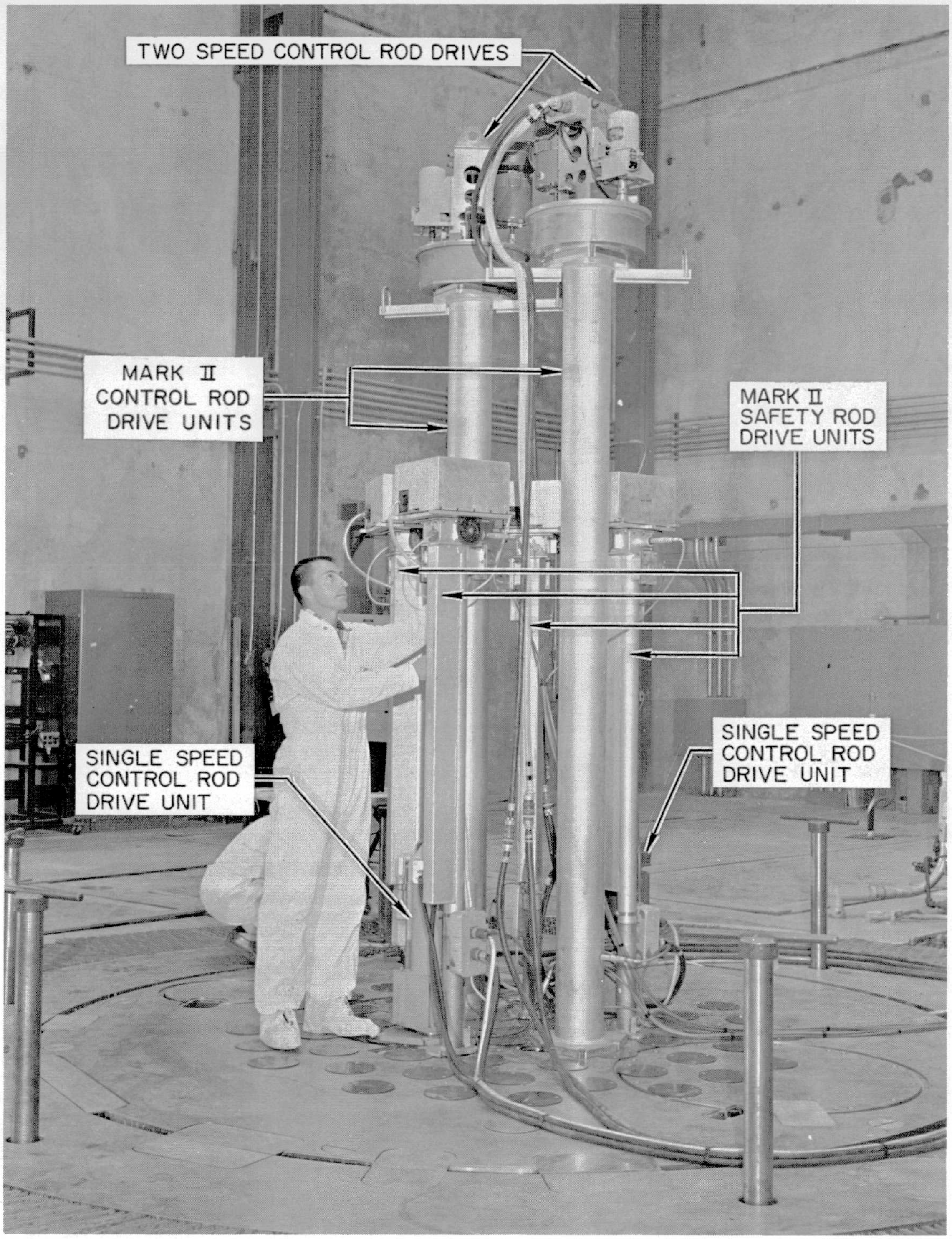

Figure 1. SRE Control and Safety Rods Installed in Reactor

e) The position of the poison column must be indicated during retrieval. The rate of removal must also be indicated.

f) Limiting devices must be provided to protect the safety rod mechanism from damage due to accidental overtravel. These limiting devices must also function as electrical interlocks.

g) Maximum clearance must be provided between the thimble wall and the poison rings during dropping of the poison column to ensure against interference with the thimble wall.

h) The entire safety rod assembly must be sealed to maintain a helium atmosphere.

i) The safety rod must be fail-safe in any situation.

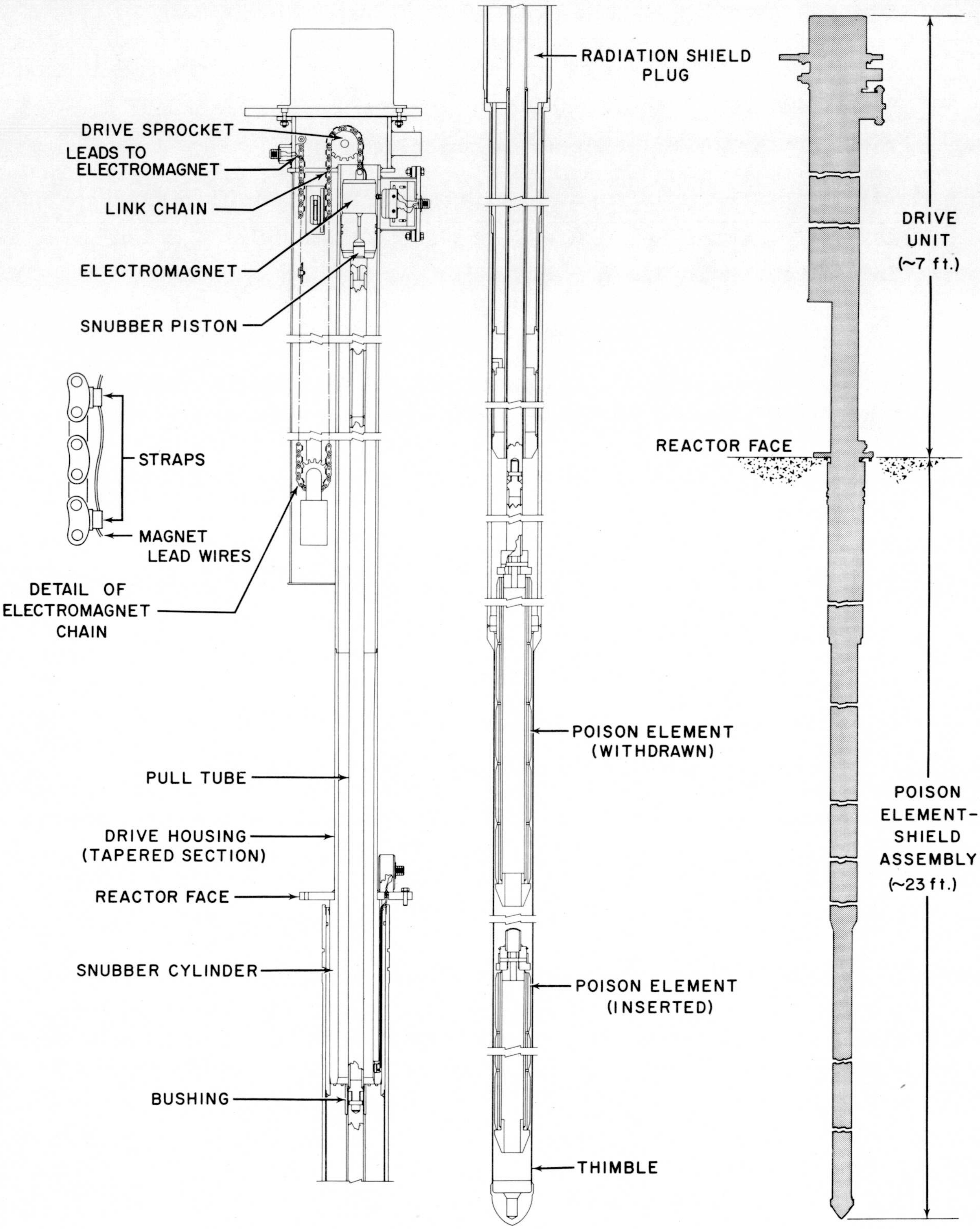

Figure 2. SRE Mark II Safety Rod

II. DESCRIPTION OF THE SRE MARK II SAFETY ROD

There are two main sections of the SRE Mark II safety rod, the drive unit and the poison element-shield assembly.

A. DRIVE UNIT

The poison-element retrieving mechanism, position-indication system, snubber, limit-switch system, and poison-release mechanism are located in the drive unit (see Figure 2).

The mechanism for holding and releasing the poison element is a d-c electromagnet which is suspended from a drive sprocket by a roller-link chain. The lead wires to the electromagnet are directed through straps on the chain links. Vertical motion is imparted to the electromagnet by rotating the drive sprocket with a reversible induction motor through a set of reducing gears and a second drive chain. The stationary end of the magnet chain is fastened to the wall of the drive housing. The slack in the chain is taken up by a counterweight hung from a sprocket. The drive motor also drives a selsyn transmitter through a gear reducer to indicate the position of the magnet. An electric brake is used to stop the drive motor.

Two limit switches are located in the drive housing. One, actuated by the chain counterweight, shuts off the drive motor when the magnet has been lowered to the snubber piston. The second limit switch is operated by the magnet and shuts off the drive motor when the poison element is completely withdrawn. A third switch, located in the bottom of the snubber cylinder, is used to indicate the position of the element and is actuated by the snubber piston when the poison element is completely inserted in the reactor core.

The drive housing consists of a tube surmounted by a rectangular box which houses the drive sprocket, chain and counterweight. The lower 18 in. of the tube serves as the snubber cylinder and is of smaller diameter than the upper end of the tube. A tapered section provides a transition from the larger to the smaller diameter.

B. POISON ELEMENT, PULL TUBE, AND RADIATION SHIELD PLUG

The poison element, pull tube, and radiation shield plug are located in the safety-rod thimble which extends vertically from the reactor loading face through the reactor core. The poison, or neutron-absorbing, element is composed of 14 boron-nickel alloy hollow cylinders strung on a pull tube. The pull tube extends through the shield assembly and is attached to the snubber piston. The snubber piston carries a set of cast-iron piston rings in each of two grooves. The top surface of the piston is chrome plated to avoid holdup of the magnet due to residual magnetism. The magnet is centered in the piston by a conical projection and mating recess.

The radiation shield plug serves as both a thermal and a radiation shield. The lower end of the plug is packed with boron carbide. The upper end of the plug receives the lower end of the snubber cylinder which is also the lower end of the drive unit. The lower end of the snubber cylinder seals against an O-ring in a groove in the plug. When the poison element is fully inserted in the reactor core, the snubber piston seals against another O-ring in a second groove in the plug. This allows removal of the drive unit without contamination of the helium atmosphere in the safety rod thimble.

The pull tube passes through a brass bushing in the plug. The diametral clearance between the bushing and the upper end of the pull tube is 0.004 in. The clearance between the bushing and the lower part of the pull tube increases to 0.125 in. The outer diameter of the radiation shield plug seals against the inner wall of the thimble with an O-ring.

C. MODE OF OPERATION

The sequence of operations for withdrawal of the safety-rod poison element begins with the actuation of the drive unit at the top of the radiation shield plug. The drive motor lowers the electromagnet until a conical protuberance on the end of the magnet mates with a recess in the top of the piston. When this occurs, the counterweight on the chain actuates a limit switch which shuts off the drive motor and energizes the electric brake. The electromagnet is energized and the drive motor is reversed, withdrawing the poison element from the reactor core. When the poison element is completely withdrawn, the magnet casing actuates a second limit switch, shuts off the drive motor, and energizes the brake. This leaves the poison element in the storage position. Any interruption of electrical power to the magnet during withdrawal or storage will cause the poison element to drop.

After the electromagnet has been de-energized, the following events take place. The poison element, pull tube, and snubber piston begin to drop. In the upper 5-ft portion of the drive housing, a generous clearance is provided between the piston rings and the drive-housing wall. After dropping approximately 5 ft the piston enters a tapered section in the drive housing. While passing through this tapered section, the rings contact the wall and are compressed while the enlarged section of the pull tube enters the brass bushing in the radiation shield plug. At the end of the tapered section, the piston and rings enter the snubber cylinder. As the piston passes through the snubber cylinder, the kinetic energy of the falling poison element is expended in compressing the gas in the snubber cylinder. When the poison element has come to rest, the snubber piston actuates the switch in the snubber cylinder indicating that the poison column is fully inserted in the reactor core.

III. DESCRIPTION OF DETAILED TESTS OF PROTOTYPE ROD

A. MAGNET TESTS

1. Induced Voltage

The first test on the magnet was made to determine the magnitude of the induced voltage caused by an interruption of the magnet current. A 1-1/2-v battery was connected across the magnet coil through a switch. When the switch was opened, a 75-v surge was observed with a cathode-ray oscilloscope. This indicated that induced voltages approximately 50 times the operating voltage of the magnet were to be expected.

An inductance of 200 h was calculated from the known resistance of the magnet coil, 3000 ohms, and the observed rate of current buildup after closing the switch. Capacitors were then added across the coil to tune it to parallel resonance at 20 cps. From this capacitance, an inductance of 180 h was calculated.

2. Magnet Holding Force

The holding force of the magnet was determined by varying the magnet current and measuring the force required to separate the piston from the magnet with a 0- to 200-lb spring scale. At the rated 50 ma, the magnet supports 150 lb. The holding force varied linearly with the current until saturation was approached at approximately 80 ma and a holding force of 200 lb.

3. Spark Suppression

To cause 50 ma to flow through the magnet coils, 150 v was required. With the induced voltage approximately 50 times greater, sudden interruption of the current could produce a destructive 7500-v surge. Because the electrical leads and connectors were rated for 1000 v, spark suppression was necessary. The spark suppression circuit used consisted of two parallel 0.01-mfd, 5000-v capacitors connected in series with a 1000-ohm resistor.

A Minneapolis-Honeywell A-1 safety amplifier is used to control the magnet current with the magnet coil in the plate circuit of a 6CD6 electronic vacuum tube. Leakage to ground from the magnet lead attached to the plate of the 6CD6 vacuum tube could cause current flow to bypass the control tube. Such leakage could result from the breakdown of insulation caused, for example, by the high induced voltages. An overcurrent relay was originally provided in the amplifier circuit to protect the circuit from leakage, but a situation could have arisen where leakage was sufficient to energize the magnet but not to trip the relay. This situation was alleviated by the installation of spark suppression resistors across the magnet coil. Their resistance decreases rapidly with an increase in voltage. The resistors limit the voltage surge to less than 400 v which is below the rated capacities of the connectors and the wire insulation. Additional protection was provided by installing fuses rated to burn out just above the normal magnet operating current.

The spark suppression circuit increased the magnet release time by permitting current to continue to flow for a short time after tube cutoff. To determine the release time with spark suppression, the magnet housing was electrically insulated from ground and an electric current was passed through the magnet housing to the piston. The elapsed time between a signal to cut off the tube and the breaking of the magnet-to-piston circuit was measured with a cathode-ray oscilloscope. This time varied between 18 and 20 msec, which was considered acceptable.

B. DRIVE MECHANISM

During room-temperature tests of the prototype safety rod, the 3-phase electric drive motor, magnetic brake, and selsyn position indicator functioned properly and did not require any modification.

C. CHAIN AND MAGNET LEAD WIRES

The roller-link chain, with the original magnet leads attached, proved to be too stiff to pass over the drive sprocket smoothly. The magnet leads were 16-gage flexible thermoplastic-insulated copper wires and were larger than necessary for the 50-ma magnet current. Replacement with 22-gage wires resulted in a partial improvement in flexibility. However, occasionally while the poison column was being lowered the chain would climb part of the way up the sprocket teeth then drop suddenly, pulling the piston off the magnet. By removing alternate magnet-lead-wire straps, the chain stiffness was reduced sufficiently to allow the chain to pass over the drive sprocket smoothly.

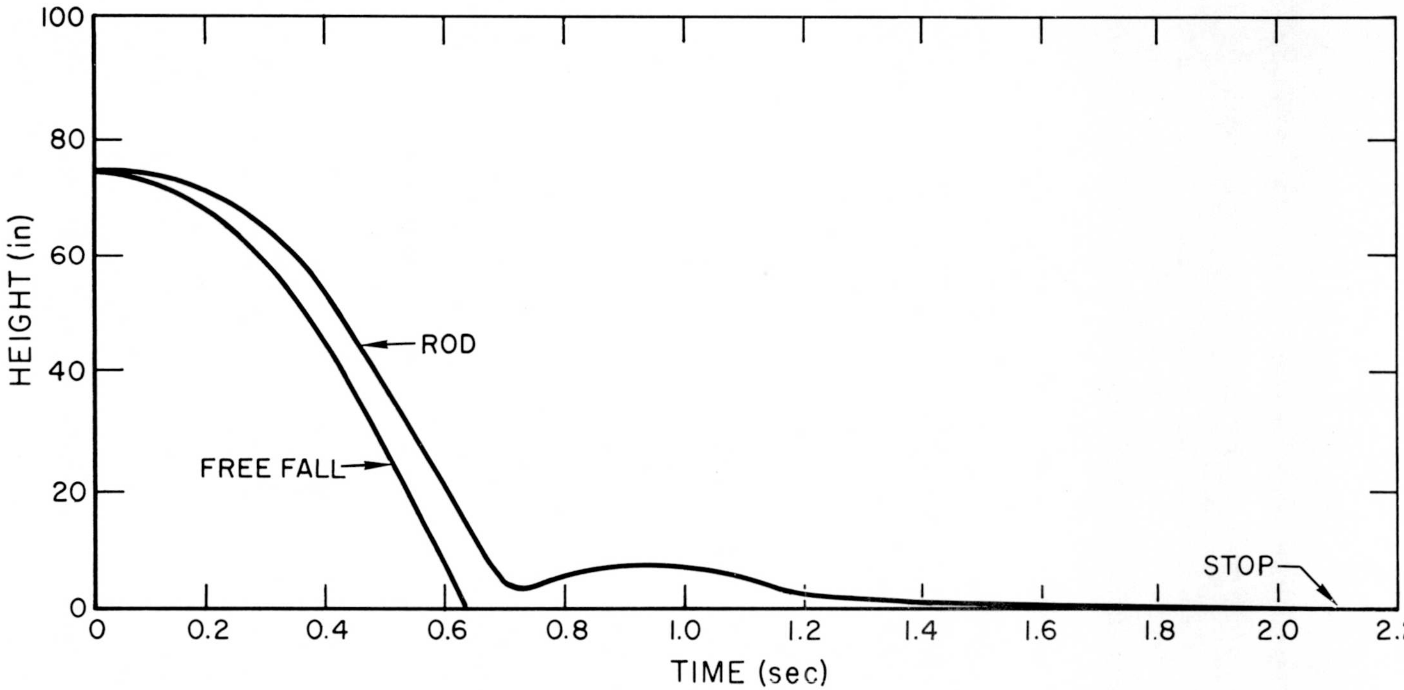

Figure 3. Rod Position vs Time

D. ELECTRICAL SEAL CONNECTORS

Electrical power for the magnet was brought into the drive housing through hermetically-sealed connectors. When electrical leakage across the connectors was detected, it was eliminated by replacing the connectors with two insulated feed-through terminals threaded into the drive housing wall and sealed by rubber O-rings.

E. LIMIT SWITCHES

Repeated raising and lowering of the energized magnet caused the up-limit switch to fail on two occasions by loss of the roller from the contact arm. This problem was found to be due to magnetic attraction between the magnet and the roller contact. The magnetic field pulled the roller contact into the path of the upward-moving magnet so that the roller was pulled off instead of being deflected sideways to shut off the motor. This was corrected by substituting a nonmagnetic stainless-steel roller contact assembly for the magnetic assembly.

F. SNUBBER

The snubber assembly was tested to determine the manner in which the piston entered the tapered section above the snubber cylinder. The piston was raised and lowered slowly through the tapered section above the snubber cylinder. No difficulties were encountered. The piston was then dropped from different heights. In one instance, when dropped from a height of 3 ft, one piston ring failed to compress into its groove and jammed between the piston and the cylinder wall. A small radius was filed from the outer edges of the piston rings and no further trouble was experienced.

G. TIME RESPONSE MEASUREMENTS

Time response and snubbing characteristics were measured with a 10-turn potentiometer attached to a spring-loaded drum rotated by a fine steel cable fastened to the piston. The drum spring exerted a drag of approximately 1 lb on the cable, which reduced by approximately 1% the dropping rate of the 65-lb poison column, pull tube, and snubber piston assembly. Voltage variations from the potentiometer were traced on a recorder. Figure 3 shows a typical trace. The poison column is seen to be inserted effectively within 0.7 sec after the signal to release the poison column. The trace indicates a slight bounce after 0.7 sec and that the poison column is at final rest after approximately 2.1 sec.

H. ENVIRONMENTAL TESTS AT REACTOR OPERATING TEMPERATURES

After the prototype was mounted in the test furnace, some test drops were made. The position indicator and the limit switches indicated that the rod was functioning properly. However, snubbing was more gentle than had been experienced in room-temperature tests. The safety rod was disassembled and the poison column was found to have become disconnected from the pull tube. The pin connecting the poison column to the pull tube had fallen out while the rod was being moved to the test furnace. The pin was replaced and tests were re-initiated.

The environmental tests consisted of 1000 drops of the poison column at a simulated reactor temperature gradient. The temperature of the prototype was 1100°F at 9 to 17 ft below the top of the timble, and dropped from 1100°F at 17 ft to 500°F at 23 ft below the top of the thimble. During the test, snubbing was observed to become increasingly rough after several hundred drops. Then snubbing suddenly improved. The safety rod was disassembled and the pull tube was found to have separated from the poison element. The pin holding the poison column to the pull tube had sheared. The pin joints were welded to strengthen the pull tube.

The loss of snubbing was found to be caused by excessive wear of the bronze bushing in the radiation shield plug through which the enlarged part of the pull tube passes. This enlarged portion, located immediately below the piston, had been chrome plated to prevent galling. However, the hard chrome plate acted as an abrasive, wearing the bushing very rapidly. After polishing the hard chrome plate and replacing the worn bushing with a brass bushing, no change in snubbing was observed over about 500 drops. The diametral clearance between the pull tube and the brass bushing is approximately 0.001 in.

The magnet insulation was found to be inadequate after the magnet failed in one instance to release the piston after cutoff of the control tube. This problem was corrected by rewinding the magnet coil and wire with heavier insulation and increasing the amount of tape used to insulate the coil from the magnet housing.

An additional interruption of the environmental tests occurred after 1100 drops when the drive motor burned out. This motor was a 220-v, 3-phase, 1/20-hp induction motor. Examination of the motor revealed no apparent cause for failure other than overheating which was due to lack of ventilation in the close confines of the sealed drive case. During the test the motor operated almost continuously. The test was far more demanding than actual reactor operation, so failure of the motor was not considered significant.

IV. STRAIN MEASUREMENTS

A. PURPOSE

Failure of the O-ring seal between the drive housing and the radiation shield plug would result in the loss of snubbing. The possibility of loss of snubbing made it necessary to determine whether the Mark II safety rods could be dropped without damage into the reactor core and stopped without deceleration through a snubber.

B. DESCRIPTION OF EQUIPMENT

The prototype rod was modified so that a pressure transducer could be installed to monitor the pressure in the snubber cylinder. An accelerometer was attached to the snubber piston to measure the acceleration of the poison element, and strain gages were mounted in the pull tube to measure the strain during snubbing of the poison element.

C. DESCRIPTION OF TEST

The following procedure was used during a drop test. The poison element was withdrawn to the storage position and then released. During the fall and snubbing cycle, the pressure in the snubber cylinder, the acceleration of the poison element, and the strain in the pull tube were recorded on an oscillograph. Drops were made with helium in the system at 1 and 2 atmospheres, and with air at 1 atmosphere. Drops were also made in air with the piston rings, pressure transducer, and snubber-cylinder O-ring seal removed to eliminate snubbing. The accelerometer was also removed to prevent it from being damaged. The results of the strain measurements are listed in Tables I and II.

D. DISCUSSION

The maximum tensile stress measured in the pull tube without snubbing was 30,000 psi. By comparing this figure with the data for yield and tensile strength of the material, the possibility of pull tube failure can be determined. The pull tube material is AISI 316 stainless steel for which data are given in Table III.

TABLE I

SNUBBING TESTS—CYLINDER PRESSURES, POISON ELEMENT POSITIONS AND DECELERATIONS

Time Seconds	Snubber Cylinder Pressure (psig)			Poison Element Position from Bottom of Stroke (in.)			Poison Element Deceleration (g's)		
	Air 0*	He 0*	He 15*	Air 0*	He 0*	He 15*	Air 0*	He 0*	He 15*
0	0	0	15	78-1/2	78-1/2	78-1/2	-	-	-
0.1	0	0	15	76	76	77	-	-	-
0.2	0	0	15	70	70	71	-	-	-
0.3	0	0	15	60	60	61	-	-	-
0.4	0	0	15	46	46	48	-	-	-
0.5	0	0	15	29	29	31	-	-	-
0.55	3	3	16	19	19	21	-	-	-
0.6	33	34	55	9	9	11	0.75	3.2	4.1
0.61	49	51	70	7-1/2	7	9-1/4	1.4	4.6	5.6
0.62	79	77	99	6	5	7-3/4	2.2	7.8	8.1
0.63	131	133	132	4	3-1/2	6	3.3	13.2	10.0
0.64	274	270	181	2-1/2	2-1/4	4-3/4	5.2	19.0	11.8
0.653	412	412	236	1	1	3-1/4	-	-	-
0.66	259	301	-	1	3/4	-	14.2	7.9	9.8
0.67	-	-	177	-	1-1/4	2-1/4	18.5	2.9	6.8
0.68	70	72	125	1-1/2	1-1/2	2-1/2	15.3	0.9	3.6
0.70	21	23	65	3-1/2	3-3/4	3-3/4	3.6	-	1.4
0.72	6	6	36	6	5-3/4	5-1/2	1	-	-

* Rod pressure before dropping (psig).

TABLE II

SNUBBING TESTS—PULL TUBE STRESSES AND CYLINDER PRESSURES

Test Conditions		Average Maximum Tensile Stress in Pull Tube (psi)	Average Maximum Pressure in Snubber Cylinder (psi)
Without Snubbing	Safety rod filled with air (1 atm) no piston rings, snubber cylinder not sealed	30,000	Not Applicable
With Snubbing	Safety rod filled with air (1 atm)	1,195	396
	Safety rod filled with helium (1 atm)	1,148	392
	Safety rod filled with helium (2 atm)	762	228

TABLE III

MECHANICAL PROPERTIES OF 316 STAINLESS STEEL

Stainless Steel	Temperature (°F)	Tensile Strength (psi)	Yield Strength (psi)
Wrought[3]	70	85,000	38,500
	600	73,000	25,500
	1100	66,500	20,500
Cast[4]	70	68,000	-
	600	50,000	-
	1100	37,000	-

Comparing the short-term tensile strength of AISI 316 stainless steel in the cast condition with the maximum tensile stress measured in the pull tube, it can be seen that there is a definite possibility of a break occurring in a weld in a pull tube if the Mark II safety rods are dropped without snubbing when the SRE is operating at full power. Because the tensile strength of the wrought material is much higher then that of the cast material, there is a smaller possibility of tubing failure. The yield strength of this steel is less than the maximum stress from an unsnubbed drop at temperatures above 300°F.[3]

The average maximum tensile stress in the pull tube when the rod was dropped in air at 1 atmosphere was 1195 psi, in helium at 1 atmosphere the stress was 1148 psi, and in helium at 2 atmospheres was 792 psi. The short-term strength of cast AISI 316 stainless steel at 1100°F (Table III) is 30 to 50 times greater than any of the above values. Therefore, there is no danger of the pull tube failing when the rod is operated with proper snubbing.

The pressures measured in the snubber cylinder are so low that there is no possibility of rupturing the snubber cylinder.

During drops with snubbing, the poison column falls to a point 1 in. from full insertion in 0.65 to 0.66 sec after the poison column is released. The poison column then bounces upward approximately 5 in. and comes to rest approximately 2 sec after being released.

V. CONCLUSIONS AND RECOMMENDATIONS

The Mark II safety rods are reliable and adequate for extended use in SRE, provided they are not operated without snubbing. The maximum tensile stress measured in the pull tube without snubbing was 30,000 psi. There is a definite possibility of a pull tube failure at temperatures above 600°F (the pull tube temperatures reach a maximum of 1100°F). This mode of rod failure is not "fail-safe" if the poison element punctures the thimble wall or breaks off the lower end of the thimble. Yielding of the material in the pull tube will occur at temperatures above 300°F.

The maximum tensile stress measured in the pull tube with snubbing was below the yield strength of the material by a factor of at least 15. With snubbing there is no possibility of pull tube failure under all anticipated operating conditions if the pressure in the snubber cylinder is 1 atmosphere or above before a drop.

As of December 1958, the SRE Mark II safety rods have been installed in the SRE for more than 19 months. During this time, they have been dropped approximately 100 times and no major difficulties have been encountered.

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